Photoacoustic Tomography: Ultrasonically Beating Optical Diffusion and Diffraction

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102D

Lihong V. Wang, Ph.D., Gene K. Beare Distinguished Professor
Optical Imaging Lab, Dept. of Biomedical Engineering, Washington University in St. Louis
Email: lhwang [at] biomed [dot] wustl [dot] edu; URL: http://oilab.seas.wustl.edu

We develop photoacoustic tomography technologies for in vivo functional, metabolic, molecular, and histologic imaging by physically combining non-ionizing electromagnetic and ultrasonic waves. Broad applications include early-cancer detection and brain imaging. Unlike ionizing x-ray radiation, non-ionizing electromagnetic waves such as optical and radio waves pose no health hazard and reveal new contrast mechanisms. Unfortunately, electromagnetic waves in the non-ionizing spectral region do not penetrate biological tissue in straight paths as x-rays do. Consequently, high-resolution tomography based on non-ionizing electromagnetic waves alone such as confocal microscopy, two-photon microscopy, and optical coherence tomography is limited to superficial imaging within approximately one optical transport mean free path (~1 mm in the skin) of the surface of scattering tissue. Ultrasonic imaging, on the contrary, provides good image resolution but suffers strong speckle artifacts as well as poor contrast in early-stage tumors. Ultrasound-mediated imaging modalities that combine electromagnetic and ultrasonic waves can synergistically overcome the above limitations. The hybrid modalities provide relatively deep penetration at high ultrasonic resolution and yield speckle-free images with high electromagnetic contrast.

In photoacoustic computed tomography, a pulsed broad laser beam illuminates the biological tissue to generate a small but rapid temperature rise, which leads to emission of ultrasonic waves due to thermoelastic expansion. The short-wavelength pulsed ultrasonic waves are then detected by unfocused ultrasonic transducers. High-resolution tomographic images of optical contrast are then formed through image reconstruction. Endogenous optical contrast can be used to quantify the concentration of total hemoglobin, the oxygen saturation of hemoglobin, and the concentration of melanin. Melanoma and other tumors have been imaged in vivo. Exogenous optical contrast can be used to provide molecular imaging and reporter gene imaging.

In photoacoustic microscopy, a pulsed laser beam is focused into the biological tissue to generate ultrasonic waves, which are then detected with a focused ultrasonic transducer to form a depth resolved 1D image. Raster scanning yields 3D high-resolution tomographic images. Super-depths beyond the optical
diffusion limit have been reached with high spatial resolution. Super-resolution beyond the optical diffraction limit has also been achieved recently. The following skin image was acquired in vivo in a mouse using optical-resolution photoacoustic microscopy.

The annual conference on this topic has been doubling in size approximately every three years since 2003 and has become the largest in SPIE’s Photonics West as of 2009.

Selected publications


Biography of Lihong V. Wang, Ph.D.

Lihong Wang earned his Ph.D. degree at Rice University, Houston, Texas under the tutelage of Robert Curl, Richard Smalley, and Frank Tittel. He currently holds the Gene K. Beare Distinguished Professorship of Biomedical Engineering at Washington University in St. Louis. His book entitled “Biomedical Optics: Principles and Imaging,” one of the first textbooks in the field, won the 2010 Joseph W. Goodman Book Writing Award. He also coauthored a book on polarization and edited the first book on photoacoustic tomography. Professor Wang has published 400 peer-reviewed journal articles and delivered 385 keynote, plenary, or invited talks. His Google Scholar h-index and citations have reached 88 and 30,000, respectively. His laboratory was the first to report functional photoacoustic tomography, 3D photoacoustic microscopy (PAM), the photoacoustic Doppler effect, photoacoustic reporter gene imaging, focused scanning microwave-induced thermoacoustic tomography, the universal photoacoustic or thermoacoustic reconstruction algorithm, frequency-swept ultrasound-modulated optical tomography, time-reversed ultrasonically encoded (TRUE) optical focusing, sonoluminescence tomography, Mueller-matrix optical coherence tomography, optical coherence computed tomography, and oblique-incidence reflectometry. In particular, PAM broke through the long-standing diffusion limit to the penetration of conventional optical microscopy and reached super-depths for noninvasive biochemical, functional, and molecular imaging in living tissue at high resolution. His Monte Carlo model of photon transport in scattering media is used worldwide. He has received 36 research grants as the principal investigator with a cumulative budget of over $44M. Professor Wang is a Fellow of the AIMBE (American Institute for Medical and Biological Engineering), IEEE (Institute of Electrical and Electronics Engineers), OSA (Optical Society of America), and SPIE (Society of Photo-Optical Instrumentation Engineers). He is the Editor-in-Chief of the Journal of Biomedical Optics.
He chairs the annual conference on Photons plus Ultrasound, and chaired the 2010 Gordon Conference on Lasers in Medicine and Biology and the 2010 OSA Topical Meeting on Biomedical Optics. He is a chartered member on an NIH Study Section. Wang serves as the founding chairs of the scientific advisory boards for two companies commercializing photoacoustics. He received NIH’s FIRST, NSF’s CAREER, NIH Director’s Transformative Research, and NIH Director’s Pioneer awards. He was awarded the OSA C.E.K. Mees Medal, IEEE Technical Achievement Award, and IEEE Biomedical Engineering Award for seminal contributions to photoacoustic tomography and Monte Carlo modeling of photon transport in biological tissues and for leadership in the international biophotonics community. An honorary doctorate was conferred on him by Lund University, Sweden.

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